JUNE 3RD 2020 EEMS059

U.S. DEPARTMENT OF ENERGY SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

CAV 7A.3.1.2 CACC DEVELOPMENT FOR CARS WITH DIFFERENT POWERTRAINS

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VEHICLE TECHNOLOGIES OFFICE ANNUAL MERIT REVIEW JUNE 1-3, 2020

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OVERVIEW

- **Timeline**
  - **Start date:** Sept 1 2018
  - **End date:** July 31 2020
- **Budget**
  - **Total project funding: $850K**
    - **100% DOE/VTO**
  - **Funding for FY 2018: $500K**
    - **LBL: $300K**
    - **ANL: $100K**
    - **INL: $100K**
  - **Funding for FY 2019: $350K**
    - **LBL: $100K**
    - **ANL: $250K**

- **Barriers**
  - **How to develop the CACC/Platooning capability for different vehicle types and powertrains in a generic approach**
  - **Data support would be necessary for microscopic mixed traffic modeling with CAVs with different powertrains, and its mobility and energy consumption evaluation**
- **Collaboration**
  - **LBNL (project lead)**
  - **ANL**
  - **INL**
  - **Output to EEMS031, micro traffic simulation**

RELEVANCE

- **Objectives:** To develop CC/ACC/CACC (Cooperative Adaptive Cruise Control) capabilities for 3 passenger cars with different powertrains. Those vehicles will be able to run in public traffic with Level 1 automation – a Driver Assistance System
- **Relevance:** Vehicle control capabilities for CAVs (Connected Automated Vehicles) need to be developed for field test:
  - Test of CACC vehicles on freeway and arterials for data collection to capture the dynamic interaction between CAVs manually driven vehicles
  - Using test data for the modeling vehicle-following behavior in microscopic level for simulation of mixed traffic, which will support the simulation in all upper levels
  - To simulate energy consumption
  - To test energy consumption and mobility in real traffic or appropriately created (controlled) environment with virtual traffic through real-time

MILESTONES

Milestone Name/Description	Criteria	End Date	Status
• Q2: CACC system development report/update on realistic operation;	Integrated CACC system including control computer, DSRC, remote sensor, upper and lower level control.	6/30/2019 1/31/2020	Delayed Accomplished
• Q4: workable CACC system for 3 passenger cars with different powertrains;	Initial track test results for 3 CACC cars.	12/15/2019 4/20/2020	Delayed 95% Accomplished
• Q4: multi-vehicle experimental LD CACC platform onto which varying CACC strategies can be validated, refined, and evaluated;	3 cars with CACC capabilities, which can be driven at low and high speed	12/15/2019 4/30/2020	Delayed 80% accomplished

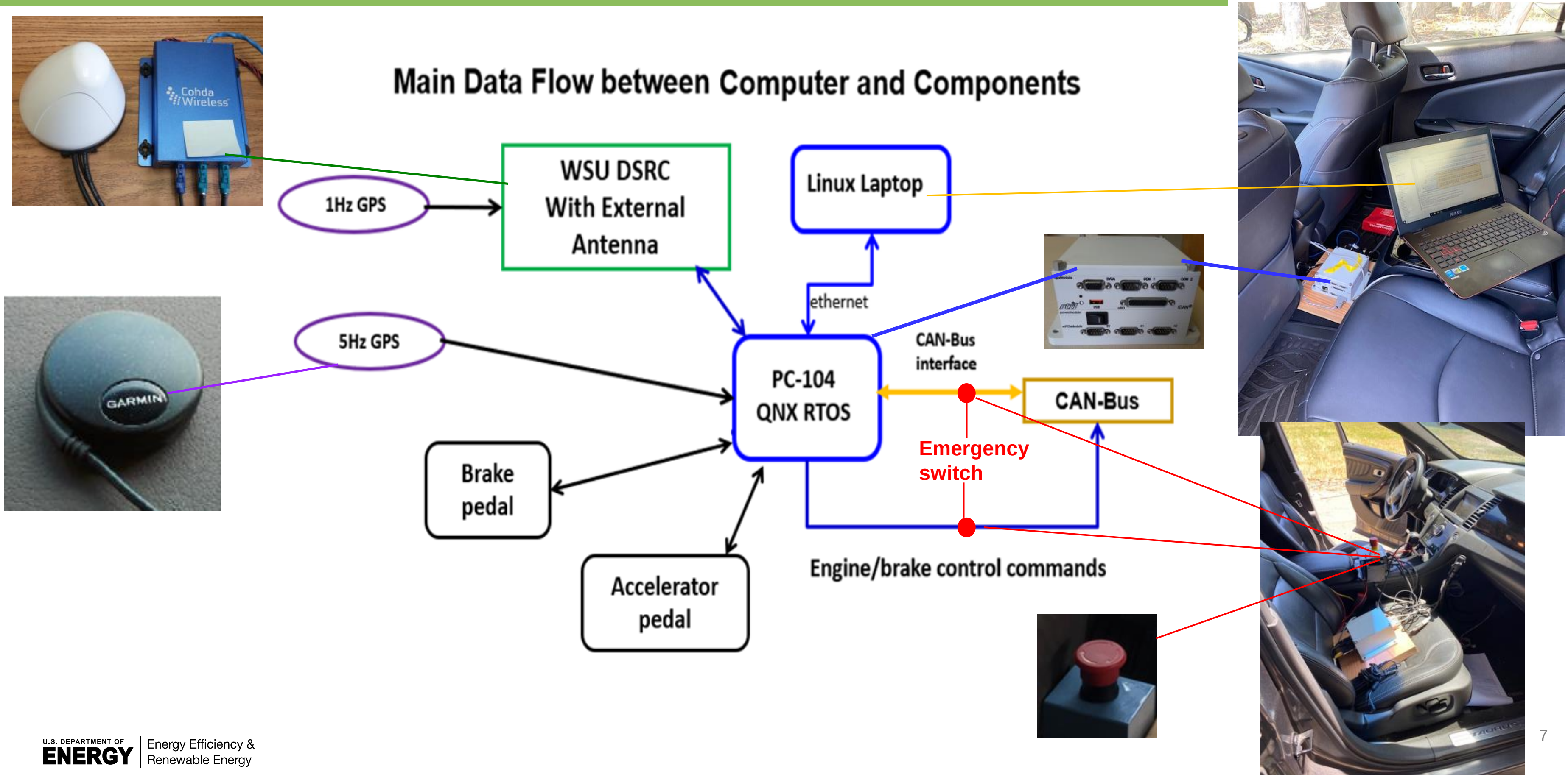
APPROACH

- Vehicle instrumentation
  - lower level interface with CAN Bus, and accelerator and brake pedals
  - Install PC-104 Control Computer, DSRC, circuiting, GPS, data acquisition, …
- Developing Torque Mapping for control actuation
- Installing driver for DSRC packet passing
- Developing vehicle dynamics modeling and CACC
- Control design, implementation and system integration
- Developing DVI (Driver Vehicle Interface)
- Preliminary test on test track, control tuning, high speed field test

GENERIC CACC SYSTEM DESIGN

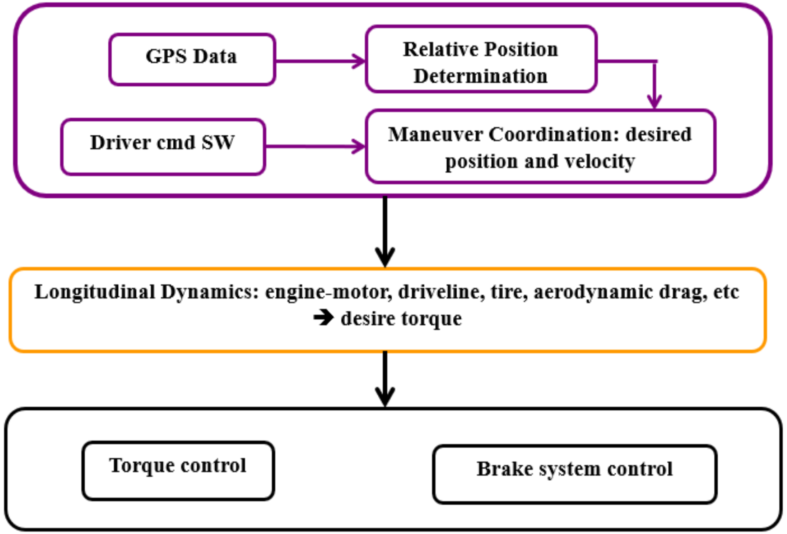
- Generic in the following sense
  - For all vehicle types: passenger cars, buses and HD trucks
  - For all power trains
  - For all make and models
  - For CC/ACC/CACC/Platooning
  - For all remote sensor type
  - For all low-level interfaces
  - Control the vehicle almost as it is (not to make physical change) except the DSRC and lower level interface unit added; the lower level control needs to be handled individually according to the vehicle make/model/year.

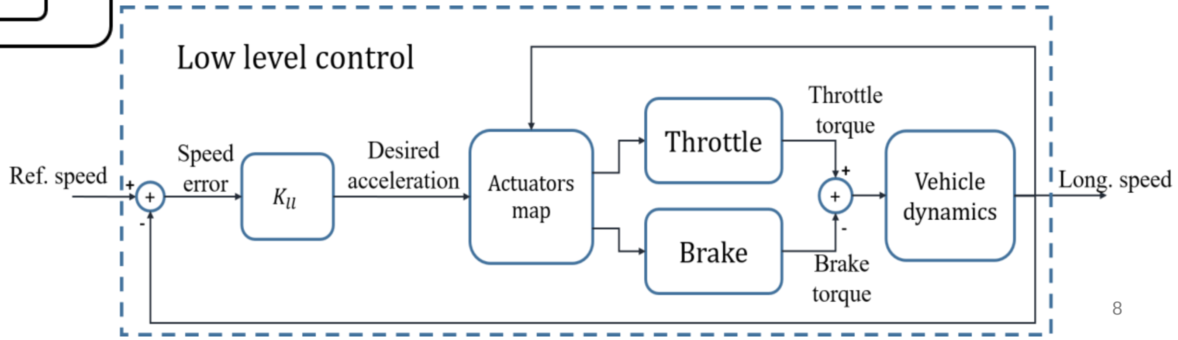
GENERIC CACC SYSTEM DESIGN



GENERIC CACC SYSTEM DESIGN

CACC System Software Structure





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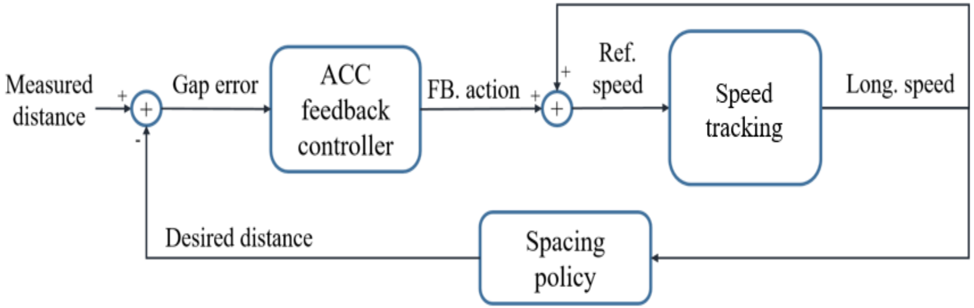
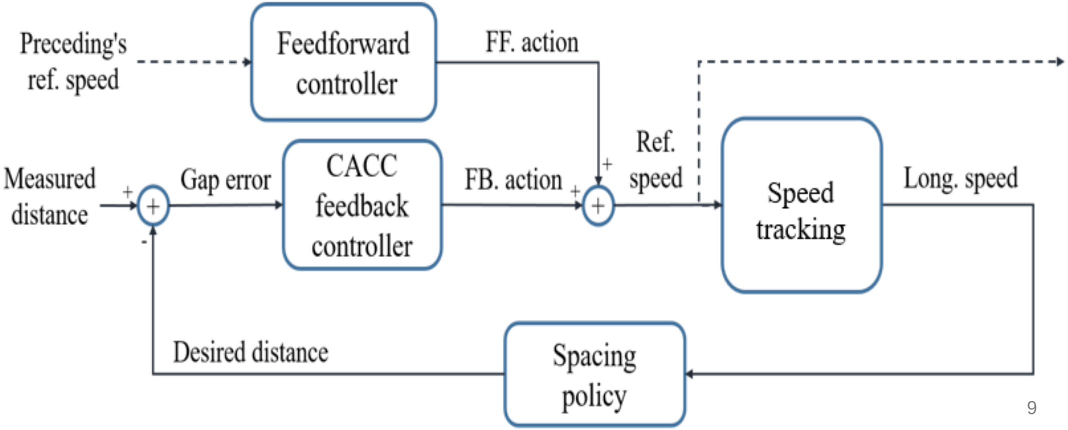
ACC AND CACC CONTROL SYSTEMS

- Spacing policy to keep constant Time-Gap
- Providing a lead-phase to the closed loop which increases gap regulation stability
- Rejecting noise and high frequency disturbances with double-order filtering on the controller output
- Limiting control effort to exist on low-to-middle frequencies and avoiding possible actuators' saturation
- The only difference between ACC & CACC is in the Feedforward controller

ACC DIAGRAM

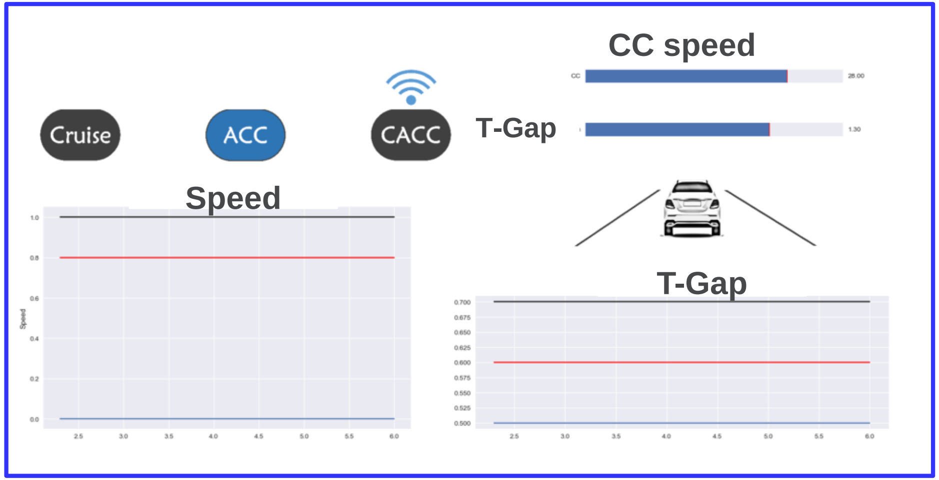


CACC DIAGRAM

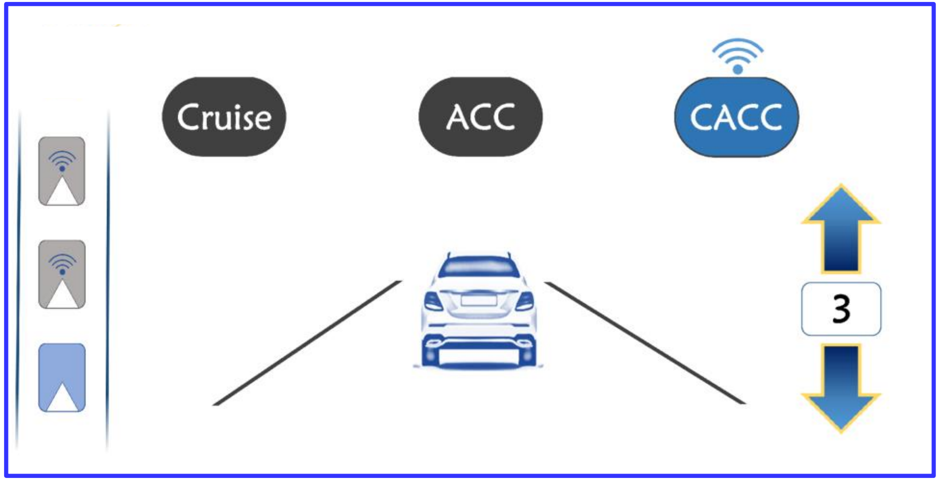


DRIVER VEHICLE INTERFACE (DVI)

- DVI for the CACC developers



- DVI for other drivers



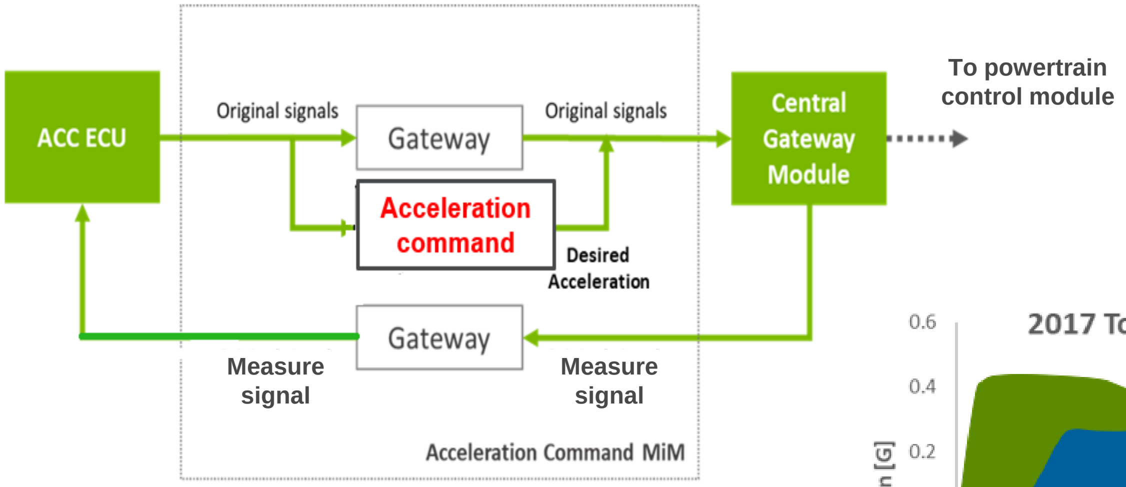
CONTROL ACTUATION STRATEGIES

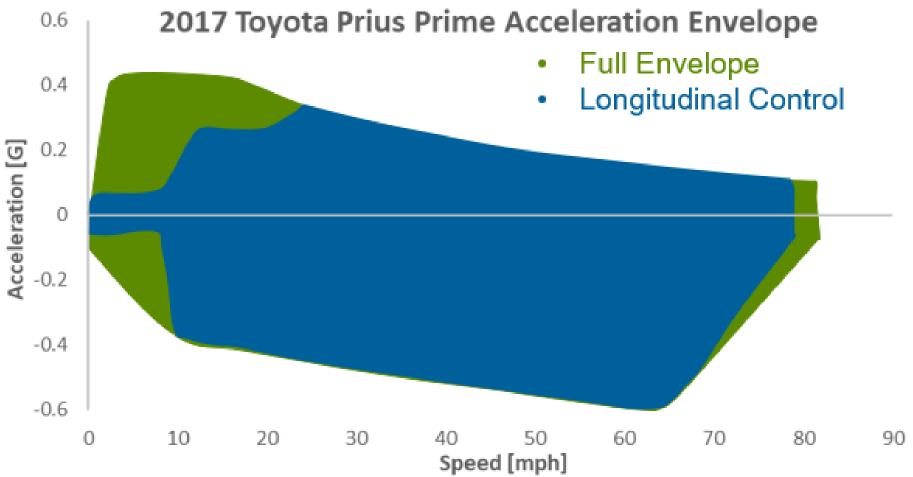
- **Challenges**: **Vehicles (make/model) have different way for low level control actuation**

Veh Model	Powertrain Type	Acceleration control through ACC & CAN Bus	Acceleration control through accelerator pedal defleciton	Deceleration control through ACC & CAN Bus	Deceleration control through brake pedal deflection	Comments
2017 Toyota Prius	Hybrid Parellel	Yes	Yes; through a direct analog voltage ; for whole speed range; and accleration range the driver can achieve; the deceleration is limited to > -5.9 [m/s^2]	Yes	N. A.	acceleration control through pedal may have less delays
2014 Honda Accord PHEV	Hybrid Serial	N. A.	Yes; through a direct analog voltage ; for whole speed and accleration ranges the driver can achieve	N. A.	Yes; through CAN; for whole speed and deceleration range the driver can achieve	acceleration and deceleration controls through accelerator/brake pedals may have less delays
2013 Ford Torus	IC Engine	Yes; for speed over 19 [mph]; max acceleration < 2 [m/s^2]	Yes; through a direct analog voltage ; for whole speed and accleration ranges the driver can achieve	Yes; for speed over 19 [mph]; max deceleration > –3.1 [m/s^2]	N. A.	acceleration control through pedal may have less delays

2017 TOYOTA PRIUS LOWER LEVEL CONTROL

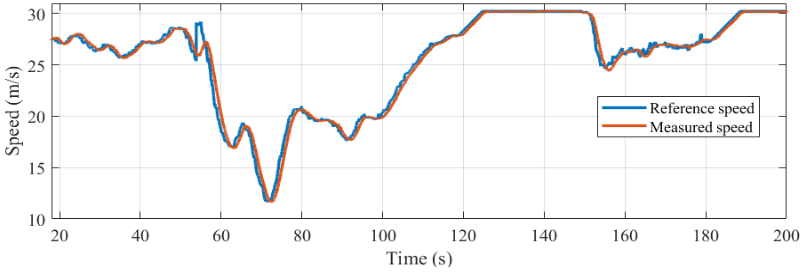
Lower Level Longitudinal Control Actuation Schematic

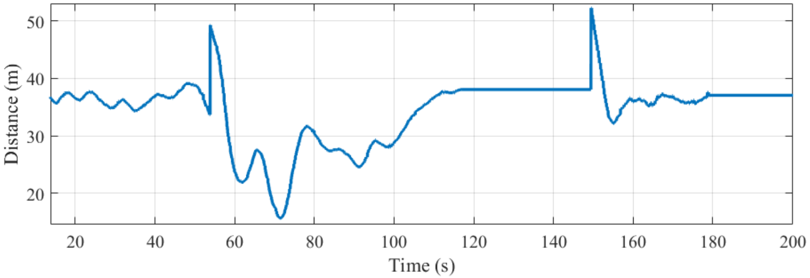




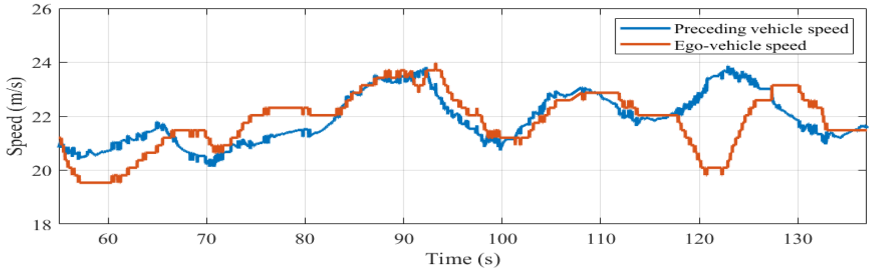
HIGH-SPEED TEST RESULTS ON FREEWAY

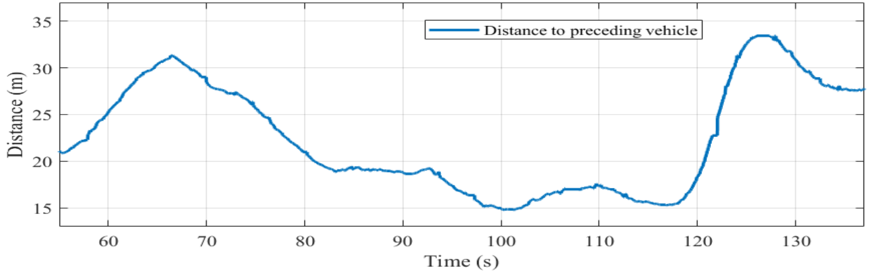
VEH 1 IN ACC: SPEED AND DISTANCE AND TRACKING

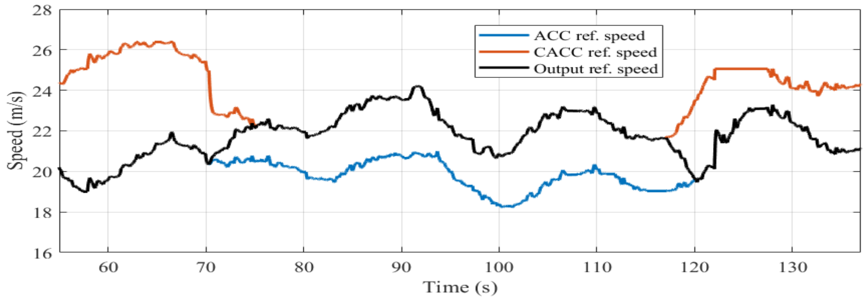




ACC/CACC: DISTANCE/SPEED TRACKING AND TRANSITION







The 2nd vehicle (right plot) switching between ACC and CACC is necessary when another vehicle cut-in (changing to ACC) and cut-out (changing back to CACC); this is for functionality development.

RESPONSES TO PREVIOUS YEAR COMMENTS

- The project team is encouraged to partner with OEMs for low-level interface work to control the subject vehicles.
  - Our experience indicated that this would be very difficult since this would touch very low-level proprietary information. OEMs usually would not support doing that.
- Proposed future research: The migration of safety risks in multi-vehicle track tests in complex tasks should be planned.
  - Agreed. It is important, but NHTSA has several programs focusing on this topic.
- The reviewer recommended focusing on areas that will help understand energy opportunities.
  - Agreed. The team proposed research into this issue in two aspects: (a) examining four main energy models for microscopic mixed traffic simulation; (b) using the experimental data of this project to improve/establish energy consumption models for vehicles with different powertrains.

RESPONSES TO PREVIOUS YEAR COMMENTS

- Consider writing a paper addressing cyber physical security concerns that many people with the right skills could also hack their cars to add functionality like this.
  - Everything would have two facets. What we did was to support the development of a Generic Control Approach which could be applied to automation of any vehicle types. This “hack” approach may not be feasible for individual since a dynamometer would be necessary for building a accurate torque mapping for CACC actuation.
- The reviewer remarked safety assessment incorporated to qualitatively or quantitatively assess safety of various scenarios ultimately modeled.
  - NHTSA has several programs/projects working in this field.
- The reviewer would expect OEMs to take an “optimize for my vehicle first” approach, which is not a system optimum, so the current research could one day lead to a list of CACC behavior standards (basically, everyone might give a little for a larger benefit to society).
  - Agreed. That would be realized through proper strategies for mixed traffic management.

COLLABORATION WITH OTHER LABS

- **LBNL:**
  - –Generic ACC and CACC/Platooning system design
  - –Control system instrumentation and implementation
  - –System integration and DVI (Driver Vehicle Interface) development
  - –Field test on track and on freeway with public traffic with data collection
- **ANL:**
  - –Provided 3 vehicles with different powertrains
  - –Lower level interface and instrumentation for control actuation
  - –Developing torque mapping for each vehicle through dynamometer
- **INL:**
  - –Data analysis after field test

REMAINING CHALLENGES

- **LBNL need to accomplish:**
  - **Sorting out brake control actuation problem from PC-104 for Ford Taurus**
  - **Preliminary low-speed test for 3-car on short test track at Berkeley**
  - **Preliminary high-speed 3-car CACC tests on freeway with public traffic**
  - **Extensive high-speed track-test for performance evaluation**
  - **Expected to be accomplished before July 31st 2020 (two months after the shelter-in-place lifted)**
  - **The final products of the project include: (a) 3 CACC capable passenger cars with different powertrains; (b) field test data which can be used for modeling micro simulation; and (c) a generic CACC design and implementation approach**

PROPOSED FUTURE RESEARCH

- Developing Level 2 ~3 vehicle control capabilities for LDV/MDV/HDV:
  - Perception with fused video camera and radar/lidar: both targets/objects and road
  - Localization: to determine “where I am” in real-time with respect to road geometry
  - Lateral (steering) control, for higher level automation
- Developing other maneuver capabilities:
  - Lane keeping and lane changing
  - Merging from onramp with full coordination with mainline vehicles
  - Merging from onramp into mainline mixed traffic with both CAVs and manually driven vehicles (without full coordination)
- Integrate lower level active powertrain control with upper level CACC control to further minimize energy consumption while maintaining all require maneuver performances and string stability for automated vehicles
- Any proposed future work is subject to change based on funding levels

SUMMARY

- **ANL accomplished**
  - **Lower level interfaces**
  - **Dyno tests for torque mappings**
  - **Investigated all possible control actuation strategies**
    - **(a) interface with default ACC - using acceleration/deceleration for control actuation**
    - **(b) interface with accelerator pedal and brake pedal - using percentage deflection for control actuation**
- **LBNL accomplished:**
  - **Developed PC-104 control computer and installed on 3 cars**
  - **Generic Longitudinal Control design and implementations for three cars**
  - **Implemented longitudinal control on three cars for lower level control actuations**
  - **Built DSRC link for three cars**
  - **Developed Driver Vehicle Interface (DVI) for developer and other drivers on a laptop**
  - **System integration and validation**
  - **Preliminary low-speed test for two car on short test track at Berkeley**
  - **Preliminary high-speed ACC and 2-car CACC tests on freeway with public traffic**

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MOBILITY FOR OPPORTUNITY

FOR MORE INFORMATION

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TECHNICAL BACK-UP SLIDES

CACC VEHICLE SUMMARY

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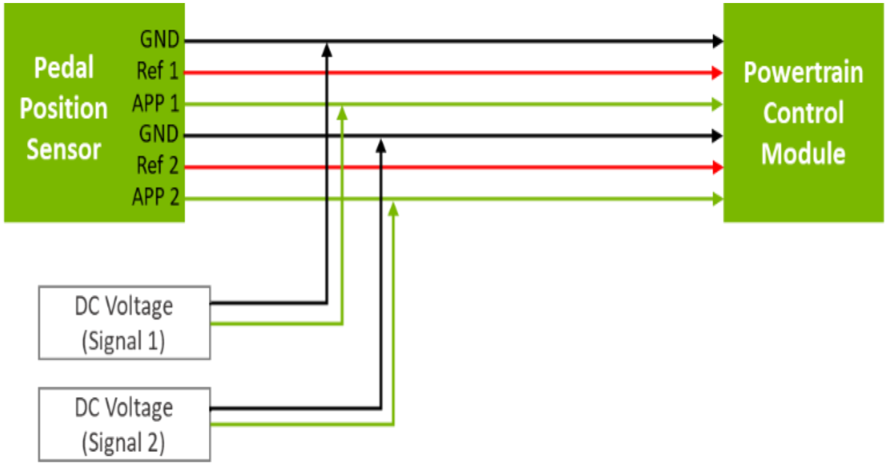
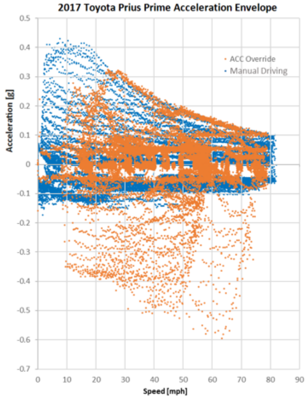
Vehicle Make / Model	Longitudinal Control Method
2017 Toyota Prius Prime PHEV & BEV	• CAN control of desired acceleration and braking (requested in [m/s^2]) • Analog voltage control of accelerator pedal (0-100%)
2014 Honda Accord PHEV	• CAN control of accelerator pedal (0-100%) • CAN control of braking (0-100%)
2013 Ford Taurus Conventional	• CAN control of desired acceleration and braking (requested in [m/s^2]) • CAN control of accelerator pedal (0-100%)

CONTROL ACTUATION STRATEGIES

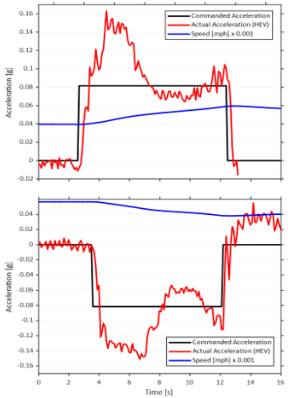
- **Circuiting and data flow for lower level control actuation**



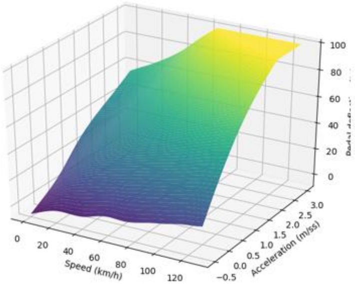
- **Acceleration envelop and pedal map; and powertrain response for Toyota Prius 2017**



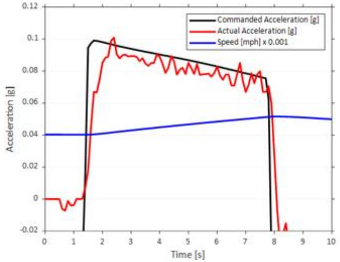
ACC override acceleration envelope for 2017 Prius Prime



Powertrain response to ACC acceleration override for 2017 Prius Prime



Accelerator pedal map for 2017 Toyota Prius Prime



Powertrain response to accelerator pedal override on 2017 Toyota Prius Prime

CONTROL ACTUATION STRATEGIES

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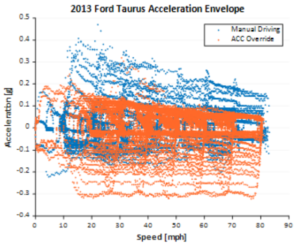
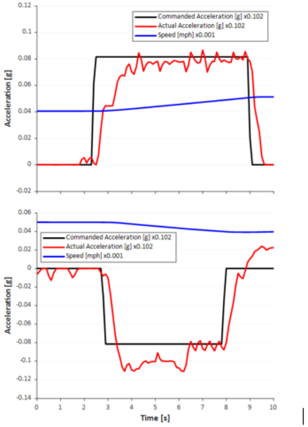
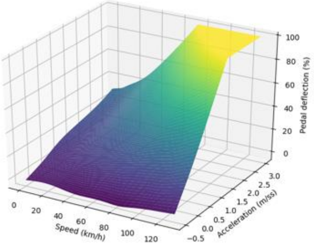
- **Acceleration envelop and powertrain response for Ford Taurus 2013**



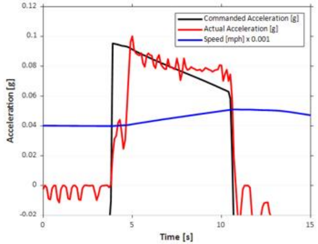
ACC override acceleration envelope for 2013 Ford Taurus



Powertrain response to ACC acceleration override for 2013 Ford Taurus

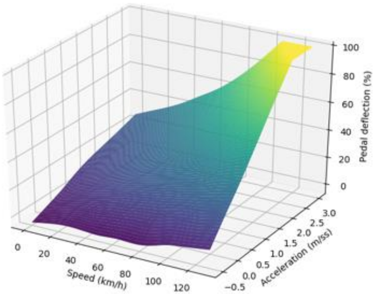


Accelerator pedal map for 2013 Ford Taurus

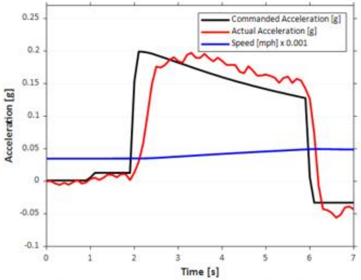


Powertrain response to accelerator pedal override on 2013 Ford Taurus

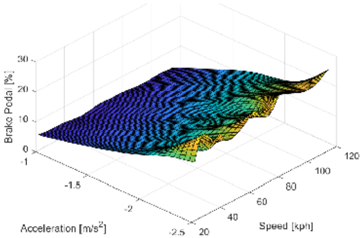
- **Acceleration/brake pedal map; and powertrain and brake response for Honda Accord 2014**



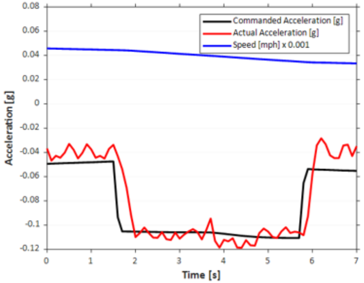
Accelerator pedal map for 2014 Honda Accord



Powertrain response to accelerator pedal override on 2014 Honda Accord



Brake pedal map for 2014 Honda Accord



Brake system response to brake pedal override on 2014 Honda Accord